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ABSTRACT

This paper describes a set of studies carried out as part of a larger project on the development of children's concepts of matter and its changes. In this paper, the impact of visibility and familiarity of the process of dissolving on children's concepts is analyzed. Two different studies with kindergarten and third grade students were carried out. The results of the study show that even children as young as four have some understanding of the conservation of substances during dissolving, although 9-10 year-olds do not have compact understanding of the process. (Contains 19 references.) (MM)

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Children's Understanding of Dissolving: The Influence of Visibility of the Process. Implications for Teaching

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In daily life, children see various processes of dissolving: sugar in the water seems disappearing while cocoa powder's dissolving seems like distributing in the water. However, both processes are called dissolving. Children develop the concepts of materials and their changes, basing on what they see and hear in daily life. Vygotsky (1934/1997) argued that the first – everyday – concepts develop from concrete perceptible instances, they are vague and depend on their referents and contexts. According to Vygotsky, children may explain the dissolving of different substances differently; it means that children's concepts of dissolving may be context-specific and dependent on the features of the solute. Other researchers stress that children's everyday concepts are incorporated into naive domain-specific theories (Au, 1994; Carey, 1991). Au (1994) argues that children possess a theory which says that matter has homogeneous structure. According to this view, substances can be broken into smaller and smaller pieces but still preserve their properties. This holds true even if the pieces of substance become so small that they are invisible. According to this view, children's understanding of dissolving is not influenced by the visibility of the process.

Later, in school, children are taught about dissolving and other physical and chemical processes. As the microscopic processes are not directly observable, the exact usage of language to describe and explain the phenomena is very important. Vygotsky (1997) referred to the concepts learnt in school through verbal definitions and explanations as scientific. However, if pupils learn new verbal explanations but do not understand them, different misconceptions that are based on their previous concepts and knowledge acquired from teaching, evolve. It has been shown that misconceptions often describe the behaviour of particles in terms of perceptual macroscopic entities (Albanese & Vincentini, 1997; Griffiths, 1994; Krnel, Watson, & Gla_ar, 1998). It means, students' concepts are still dependent on the visible side of the process. In addition, misconceptions arise due to confusing specific scientific terms with everyday language (Driver, 1985; Garnett, Garnett, & Hackling, 1995). It means that the sources of misunderstanding are the same both before school and in school.

The concept of dissolving has been studied a lot, but quite ambiguous results have been reported. Piaget and Inhelder (1941/1974) found three stages of the concept of dissolving. The youngest children thought of dissolving as of disappearance of the solute, elementary-grade pupils as of liquefaction, older pupils as of breaking or pushing larger particles into pieces. Later studies have shown that even younger children appreciate

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that substance continues to exist after it has become invisible upon dissolution (Au, Sidle, & Rollins, 1993; Rosen & Rozin, 1993). Au et al. found that 75% of the 6-year olds and 90% of the 7-year old children of the sample stated explicitly that there was still sugar in dissolution. Rosen and Rozin (1993) found no differences between various white substances in accepting the conservation of taste during dissolving and referring to the particles.

But, on the other hand, even older (9-16 year old) students' understanding of dissolving is quite unclear. They explain dissolving as disappearing, breaking up, decomposing, distribution (Prieto, Blanco, & Rodriguez, 1989), mixing (in the sense of displacement), liquefaction (Krnel et al., 1998), turning into water or combining with water (Driver, 1985; Driver, Squirer, Rushworth, & Wood-Robinson, 1995). Students think of melting and dissolving as synonyms or mix the terms up (Driver, 1985; Driver et al., 1995; Krnel et al., 1998; Lee, Eichinger, Berkheimer, & Blakeslee, 1993; Prieto et al., 1989). Children think that sugar is not the same in the dissolution (Driver, 1985).

So far, a great majority of researchers have studied the understanding of the dissolving of sugar in the water (Au, 1994; Au et al., 1993; Driver, 1985; Johnson, 1998; Lee et al., 1993; Piaget & Inhelder, 1974; Rosen & Rozin, 1993). However, dissolving of sugar is specific in several senses: children have experience with it from very early on and during the process sugar seems to disappear. Rosen and Rozin (1993) who compared the acceptance of conservation of taste and flavor during dissolving of different invisible substances (sugar, citric acid, soap powder and polycose) have carried out an exceptional study. They found that the results did not depend on substance. However, all these substances were white and became invisible during dissolving.

There are several reasons to clarify children's conceptions of dissolving. The processes of dissolving of white and colored substances appear to be different. Therefore, it is a good case to study if everyday concepts are perceptually bound (Vygotsky, 1997) or used more coherently (Au, 1994; Au et al., 1993). If they tend to be more perceptually bound, different concepts of dissolving should develop about the visible and invisible processes. In addition, everyday language misuses the terms dissolving and melting (e.g. in Estonian, dissolving of sugar is frequently called melting), giving a possibility to study the influence of everyday language on the development of concepts. As students' preliminary concepts heavily influence how they interpret the new information taught in school, it is also important to know them to design new curricula (Glynn & Duit, 1995; Schnotz, Vosniadou, & Carretero, 1999).

The studies described in the paper are carried out as a part of the larger project on the development of children's concepts of matter and its changes. In this paper, the impact of visibility and familiarity of the process of dissolving on children's concepts is analyzed. Two different studies with kindergartners and third graders were carried out. We expected that 4-10-year old children do not have clear and compact understanding of dissolving of matter and its conservation. They give incompatible answers in different tasks. These are concepts that children have developed basing on what they

see and hear in their daily life (i.e., everyday concepts) (Vygotsky, 1997). In addition, we hypothesized that children describe differently the dissolving of visible matter as compared to invisible one.

Method

Participants

The participants of the study included 66 kindergartners (21 four-year olds, 20 five-year olds and 25 six-year olds, approximately the same number of boys and girls) and 78 nine-ten-year old schoolchildren (approximately the same number of boys and girls). The participants had not received any formal teaching about the molecular structure of matter.

Procedure, tasks and coding

Children were interviewed individually. The interviewer and a child sat alone in a room. Interviews lasted for 15-30 minutes. Tasks were developed basing on the earlier research (Au et al., 1993; Driver et al., 1995). All the tasks were accompanied by demonstrations: children were shown the dissolving of different solid substances in water.

With kindergartners, four substances were used: potassium permanganate (colored and unfamiliar); cocoa (colored and familiar); sugar (white and familiar); and citric acid (white and unfamiliar). Before asking the questions, interviewer talked about the substance and its taste. Half of the children were first asked about colored substances, another half about white substances. Only two substances were used with schoolchildren: potassium permanganate (visible) and sugar (invisible and familiar) with group I and potassium permanganate and citric acid (invisible and unfamiliar) with group II.

The questions and the categorizing of answers are given in Table 1. Schoolchildren were not asked about the taste as even younger children gave mainly conservation-answers to this question.

Table 1. Questions and the categorization of the answers

Question	Non-conservation answers	Conservation answers
1. What happened with sugar (citric acid, potassium permanganate, cocoa)? /after it had been put into the water and stirred/	Disappearing, changing, I don't know	Distributing, dissolving, melting
2. Is sugar (citric acid, potassium permanganate, cocoa) still in the water? [1]	No	Yes
3. What happened to the water? /after the substance had been put into the water/	I don't know	Change in color, change in taste, mixing of substances
4. What is the taste of this? [1] [2]	The taste of the water, I don't know	The taste of the substance or correct evaluations

[1] Children had to explain their answer;

[2]These questions were not asked from schoolchildren.

Results

As no age differences occurred inside the younger group, the results will be analyzed together in this group. The results of the younger and older children will be compared.

Conservation of taste during dissolving

The far majority of children stated that the solution had the taste of the substance (82% for sugar and citric acid, 83% for potassium permanganate and 88% for cocoa). No significant differences in conservation-answers were found between substances and between children who first saw the dissolving of colored as compared with those who saw white substances. Children explained their answers in three ways: "I saw that you put the substance into the water", "I have tasted it" and "mother/father has taught it". Significantly less children explained their answers to potassium permanganate, as compared with cocoa ($Q=11,63$, $p<.001$) and sugar ($Q=5,54$, $p=.018$). Of those 43 children who gave conservation-answers to all the substances, less explanations were given to unknown substances: potassium permanganate as compared with sugar ($Q=12,00$, $p<.001$) and cocoa ($Q=7,14$, $p=.002$); citric acid as compared with sugar ($Q=5.44$, $p=.02$) but not with cocoa.

Dissolving of different substances in the water and their conservation

Kindergartners

Figure 1 provides the distribution of answers (in percentage) to the question "What happened with the substance?" for all the four substances. It is seen that few children used the terms "melting" and "dissolving" for white substances. The majority of children talked about dissolving of colored substances as of distribution but of white substances as of disappearing or changing (i.e. gave non-conservation answers). From these answers, we can infer that children may think that colored substances conserve in the water while white substances don't. The difference in conservation-answers was significant between colored and white substances (between citric acid and potassium permanganate: $Q=12.6$, $p<0=.001$; citric acid and cocoa: $Q=12.46$, $p<.001$; sugar and potassium permanganate: $Q= 6.82$, $p=.009$; sugar and cocoa: $Q=6.55$, $p=.01$).

However, the majority of children answered to the explicit question "Is the substance still in the water?" affirmatively. There were no significant differences between the substances (64% for sugar, 74% for citric acid, 73% for potassium permanganate and 71% for cocoa). The difference between conservation-answers for different questions was significant only for citric acid ($Q=19.6$, $p<.001$). In their explanations of conservation, children told that they had seen that the substance had been put into the water. In explaining non-conservation, children stated that the substance had changed.

The descriptions of the change of the water also depended on the visibility of the substance: children referred mainly to the change in color if the colored substance was put into the water but to the taste if the white substance was put into the water (see Figure 2). Children gave also more "I don't know"-answers for white substances as

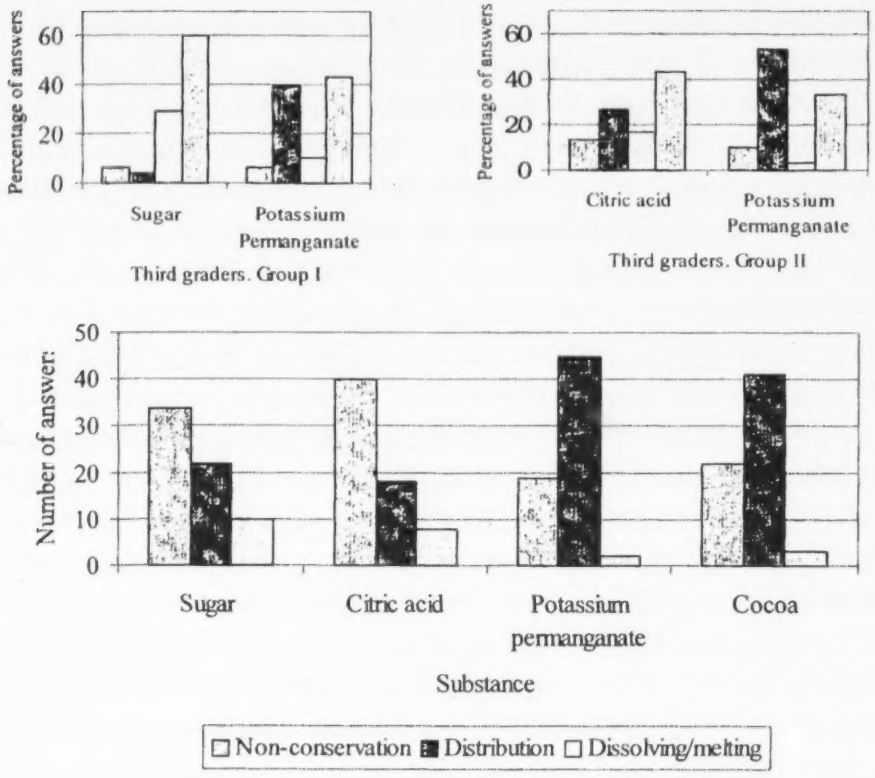

Figure 1. Distribution of answers to the question "What happened with the substance?" /after it had been put into the water/

compared with colored ones, the difference was significant between potassium permanganate and citric acid ($Q=4.76$, $p<.03$) and potassium permanganate and sugar ($Q=5.00$, $p<.03$). Those children who first saw the dissolving of colored substances referred more to the change in color for the dissolution of white substances (for citric acid $\chi^2(2)=10.35$, $p=.006$, for sugar $\chi^2(2)=5.99$, $p=.049$).

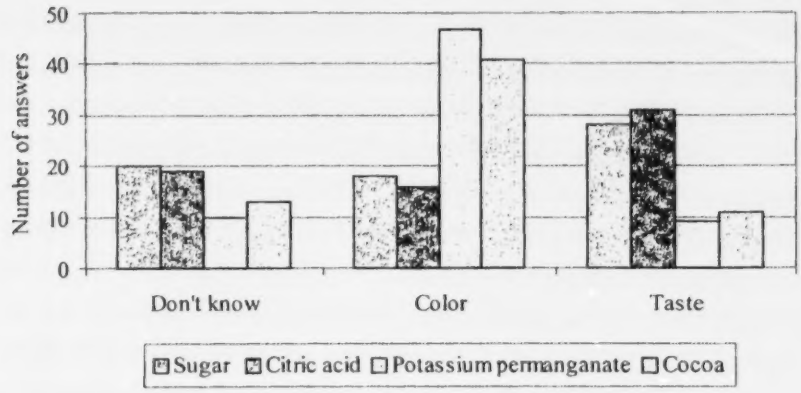

Figure 2. Distribution of answers to the question "What happened with the water?"/

Schoolchildren

The distribution of answers (in percentage) to the question "What happened with the substance?" is given in Figure 1 for both groups. It is seen that few 9-10-year old children gave non-conservation answers. The majority of children (group I) used the terms "melting" and "dissolving" to describe the process of dissolving of sugar. However, children (group II) used the terms "dissolving", "distributing" and "melting" for citric acid. Both groups used "distributing" and "dissolving" to describe the dissolving of potassium permanganate in the water.

While explicitly asked the question "Is the substance still in the water?", in group II 73% children answered affirmatively for citric acid and 77% for potassium permanganate. They explained their conservation-answers similarly to the younger group (i.e. that they saw that the substance had been put into the water). Only three children stated explicitly that the substance stays in the water after it had been put there. Also, three children stated explicitly that the substance had changed or "melted away". However, only 52% of children from group II stated that there was sugar in the water while 90% stated that there was potassium permanganate. Those children who stated that there was no sugar any more either could not explain their answers or said that sugar had changed into sugar-water. The difference between conservation-answers for different questions was significant only for sugar ($Q=16,7$, $p<.001$), also the difference in conservation-answers for the explicit question was significant between potassium permanganate and sugar ($Q=16.2$, $p<0=.001$).

When talking about what happened to the water, the far majority of children still referred to the changes in colour for potassium permanganate and taste for sugar and citric acid. Only one child said that the substances mixed.

The sequence of tasks had no impact on schoolchildren's results.

Discussion and the implications for teaching

Students learn and understand better the knowledge that can be integrated with their preliminary knowledge and everyday experience (e.g. Schnotz et al., 1999). If the knowledge taught in school differs from students' existing conceptions, different misconceptions arise (Chinn & Brewer, 1993; Driver et al., 1995). Misconceptions arise specifically easily if students' preconceptions are consistently used in various contexts and the new knowledge contradicts them in some ways. These concepts develop as a result of students' attempts to make sense of the new information, making it fit with the preliminary one (see also synthetic concepts, Vosniadou, 1992). Therefore, it is extremely important to know the concepts students hold before the formal teaching starts. In addition, Vygotsky argues that children may use words, taken from adults (from everyday language) but filled with their own meaning (see pseudoconcepts, Vygotsky, 1997). Adults usually think that children have the same meaning as they do, while in reality they have not. To improve science education, the meaning of students' preliminary concepts must be studied in more detail.

The results of the study showed that even as young as 4-year old children have some understanding of the conservation of substances during dissolving, but even 9-10-year olds do not have compact understanding of the process. Interestingly, no differences occurred between 4-6-year old children's results.

As shown before (Au et al., 1993; Rosen & Rozin, 1993), already young children appreciated the conservation of taste of the substance during dissolving. The idea of conservation was not influenced either by the visibility of the process or the familiarity of the substance (cf. Rosen & Rozin, 1993). However, more children explained their answers for familiar (as compared with unfamiliar) substances; these children referred to their experience or that the parents had taught it. But several children stated that the dissolution had the taste of the substance because the substance had been put into the water. To understand that substance conserves (at least some of) its features is important to children in the context of health: it is unhealthy and sometimes dangerous to drink contaminated water (see also Au et al., 1993).

However, children were not so consistent in their answers to other questions. It was found that children understood the dissolving of coloured and white substances differently, but the familiarity of the substance had little influence on the understanding. Kindergarteners appreciated more the conservation of coloured substances (as compared with white substances) after these had dissolved in the water. It is just what is seen: the dissolving of the coloured substance seems like staying in the water while the dissolving of white substances seems like disappearing. Even schoolchildren were inconsistent in their answers: more students stated explicitly that there was no sugar in the water, as compared with those who stated that there was no potassium permanganate.

The main differences, occurring in all the groups, were determined in the word use: the usage depended on the features of the dissolving substance. In all age groups, chil-

dren used more frequently the word "distributing" to describe the dissolving of visible substances. It seems that the children take use of the visible side: the dissolving of potassium permanganate/cocoa is really seen as the matter distributing in water. Even more, when talking about what happens to the water, children referred to the visible change in the colour, but did not talk about distributing of the substance and the water (cf. Driver et al., 1995; Driver 1985; Lee et al. 1993).

While kindergarteners described the process of dissolving of white substances as "changing" or "disappearing", schoolchildren described it as "dissolving" or "melting" (cf. Krnel et al., 1998; Piaget & Inhelder, 1974; Prieto et al., 1989). The word "melting" is widely used in Estonian in everyday language to describe the dissolving of sugar (e.g., "sugar melts in coffee") (cf. Driver, 1985). Children learn earlier the term "melting": the younger children used it more than the term "dissolving". The older children used more frequently the correct term "dissolving", especially for white substances, but the term "melting" was also used. However, even these children could not explain in other words what they meant by this term. The majority simply stated that they could not explain, others described it as "melting" (for "dissolving") or "dissolving" (for "melting"), but also as "disappearing" and "changing" (cf. Driver et al., 1995; Lee et al., 1993; Prieto et al., 1989). It seems to be the case Vygotsky (1997) described as a pseudoconcept: a word taken from adults but with different meaning and structure. It may be that children think of dissolving as of changing the substance into the new one (e.g., into sugar-water) not as of distributing of the substance and water (cf. Driver, 1985). It was found that children referred to the change in the water's taste (or colour), only one schoolchild talked about mixing.

Our results also showed that children did not have the integrated knowledge of dissolving, which was used consistently for solving different tasks and in different contexts (but see Au, 1994). The results are consistent with the approach of Vygotsky (1997), who states that everyday concepts are perceptually bound and context-dependent, and influenced by the everyday language use. Even the sequence of tasks influenced the results of some tasks in the younger group. Also, in all the groups, the differences occurred between white and coloured substances.

To conclude, it seems that before having learnt the topic in school, children's concepts of the process of dissolving of coloured and white substances may be different. Therefore, it seems important to base in teaching not only on some specific cases (usually, sugar in water) but to give different examples (coloured, white, familiar and unfamiliar substances) and tasks. It was also found that although children use the words melting and dissolving, the meaning of these terms might be different from their scientific meaning. If children's meaning is different from scientific, they interpret the information taught in school differently, consequently, various misconceptions may arise. If dissolving means changing, children think of dissolving as of changing of substance into new one. For sure, the meaning of the words "melting" and "dissolving" needs the further clarification.

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Conceptual development, dissolving, conservation, children, science education

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